UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

REPLY TO THE ATTENTION OF:

JAN 07 2003

SE-5J

VIA FACSIMILE (847) 279-2510 AND U.S. MAIL

Mr. Richard Berggreen
STS Consultants, Ltd.
750 Corporate Woods Parkway
Vernon Hills, Illinois 60061

RE: Lakeshore East Borehole Calculation Adjustment for Water

Dear Mr. Berggreen:

Enclosed is a copy of a memorandum that details the calculations to adjust for water surrounding the borehole casings for the sampling work performed on October 29, 2002. These calculations show there were nine data points that exceeded the modified cleanup criterion. According to the development plans that have been presented to U.S. EPA, this portion of the property will be a public park owned by the City of Chicago. Therefore, your options are as follows:

1. Excavate the contaminated material;

2. Leave the contaminated material in place and implement institutional controls with the City of Chicago to prevent uncontrolled exposure and dispersion.

If you would like to discuss this matter further, please contact me at (312) 886-3601 or Mary Fulghum, Associate Regional Counsel, at (312) 886-4683.

Sincerely,

Verneta Simon

Verneta Simon
On-Scene Coordinator

Enclosure

cc: Naren Prasad, Chicago Department of Environment

bcc: Mary Fulghum C-14J, w/enclosure
Larry Jensen, SMF-4J, w/enclosure
Cathy Martwick, C-14J, w/enclosure
Fred Micke, SE-5J, w/enclosure
Linda Nachowicz, SE-5J, w/o enclosure
Debbie Regel, SE-5J, w/o enclosure

U.S. ENVIRONMENTAL PROTECTION AGENCY
SUPERFUND DIVISION
77 WEST JACKSON BOULEVARD
CHICAGO, ILLINOIS 60604

DATE: January 6, 2003

SUBJECT: Adjustment of Criterion for Borehole Measurements Below Groundwater at Lakeshore East Due to Water Around Borehole Casing

FROM: Larry Jensen, CHP
Regional Radiation Expert
Emergency Response Section #3

TO: Fred Micke
On-Scene Coordinator
Emergency Response Section #3

Verneta Simon
On-Scene Coordinator
Emergency Response Section #3

During the Removal Action at Lakeshore East, the Potentially Responsible Party's contractor, STS Consultants, reached groundwater before they had completely removed all the thorium contaminants. Because of the difficulty of locating these materials under water and because of the difficulty of ensuring that all contaminants were removed, they drove four borings into the area and conducted gamma logging (see attached map for locations).

Their data was based on calibrations for a borehole casing of steel pipe but did not allow for water between the casing and the surrounding soil. As a result, their coefficient corresponding to the cleanup criterion (5396 counts per 30 seconds for 7.2 picocuries per gram) was not directly usable for determining if subsurface material exceeded the criterion for cleanup.

In this memo I describe how I adjusted their coefficient to include 3 inches of water absorber (worst case as requested by Fred Micke, On-Scene Coordinator) and to adjust the coefficient to the Lakeshore East cleanup criterion (7.1 pCi/g). The new coefficient is 3176 counts per 30 seconds per 7.1 picocuries per gram.

As a result of this information, nine data points were found to exceed the criterion for cleanup. Specifically,

BOREHOLE	DEPTH (FEET)	MEASURED COUNT RATE (COUNTS / 30 SECONDS)
EE1	16.5	3441
EE3	7	3274
	7.5	4169
	8	4395
	8.5	3423
EE4	5.5	3624
	6	4036
	6.5	3845
	7	3514

Adjusted Cleanup Criterion = 3176 counts per 30 seconds at 7.1 picocuries per gram

Adjustment of Cleanup Criterion
to Include 3 Inches of Water

Overview of Adjustment

When gamma rays impact a medium, such as water, there will be absorption but there may also be some enhancement (or buildup). The result is found by multiplying the incoming level by an absorption factor and by a buildup factor. The effect will vary depending on the energy of the gamma ray. The total or net effect will be the sum of the individual energy-dependent values.

The equation for this calculation is not complicated. However, the parameters that go into the equation cannot be determined by direct calculation, but must be interpolated from data tables. Most of the work necessary to calculate an answer for this problem was spent interpolating from available data sets.

The result was a modified parameter corresponding count rate per 30 seconds to the site cleanup criterion, 7.1 picocuries per gram (pCi/g).

Method for Calculation of Adjusted Criterion Count Rate

The fundamental equation for this calculation was taken from the Radiological Health Handbook published by the Department of Health, Education and Welfare. However, it can be found in academic and reference texts, as well as on the internet. Specifically,

$$\mathbf{X = X_o * B * exp(-ux)}$$

where

X = the corrected count rate (counts per 30 seconds, c/30s)

X_o = the uncorrected count rate (c/30s)

B = Buildup Factor (unitless)

exp = base of natural logarithms

u = Linear Absorption Coefficient (cm^{-1})

x = absorber thickness (cm)

and further

$$ux = u/p * x * p$$

where

u/p = Mass Attenuation Coefficient (cm^2/g)

x = thickness of absorber (cm)

p = density of absorber (g/cm^3)

Calculation of Mass Attenuation Coefficients

The Radiological Health Handbook contains tables with Mass Attenuation Coefficients by gamma ray energy for a water absorber (see Table 2). The Mass Attenuation Coefficients corresponding to the principal thorium gamma ray energies (see Table 1) were found by interpolation (see Tables 3 and 4). [Gamma-ray energies were taken from Publication 38 of the International Commission on Radiological Protection, "Radionuclide Transformations, Energy and Intensity of Emissions"] The Mass Attenuation Coefficients were used to calculate the Linear Attenuation Coefficients by multiplying by the water thickness (3 inches or 7.62 centimeters) and by the density of water (1 gram per cubic centimeter) [see Table 9].

Interpolation for the Mass Attenuation Coefficients was done by two methods. As can be seen from Figure 1, the curve of Mass Attenuation Coefficient versus energy is quite concave so that there could not be any linear interpolation over many data points. It was decided to try both a least squares fit over 3 points and an interpolation over two points. The results were compared.

Table 3 shows a Least Squares Fit over three points surrounding the thorium energy. The data for the Least Square Fit came from Table 2. For example, when the energy range was selected as 150 - 300 keV, the Mass Attenuation Coefficient points were those for 150, 200 and 300 keV. The Least Squares Fit calculation was done using the website at www.physics.csbsju.edu/stats/QF_NROW_form.html.

Each Least Squares Fit was done twice, once where two points were below the thorium gamma energy and again when two points were above the thorium gamma energy. Results for these two calculations were averaged. For example with the thorium energy 238.6 keV, the Mass Attenuation Coefficients at 150, 200 and 300 keV were used in a Least Squares Fit . Then the Mass Attenuation Coefficients at 200, 300 and 400 keV were used in another Least Square Fit. The two results were averaged. These results are given in Tables 3 and 4. The two methods compare very well.

Calculation of Linear Absorption Coefficients

Interpolation for the Buildup Factors was more complicated. First the Mass Attenuation Coefficients were used to compute the Linear Absorption Coefficients by the equation

ux = (u/p) * x * p

where

u = Linear Absorption Coefficient
u/p = Mass Attenuation Coefficient
x = thickness of absorber
p = density of absorber

For each thorium energy, the Mass Attenuation Coefficient from Table 4 was used with a water thickness of 3 inches (7.62 centimeters) and a water density of 1 gram per cubic centimeter to compute the Linear Absorption Coefficients shown in Table 9.

It can be seen from Figures 2 - 5 that the Linear Absorption Coefficients are very close to linearly varying. [Data was taken from the Radiological Health Handbook.]

Calculation of Buildup Factors

Further interpolation was necessary to obtain the Buildup Factors corresponding to the thorium gamma-ray energy. Data for Buildup Factors corresponding to Linear Absorption Coefficients was given in the Radiological Health Handbook. These are tabulated in Tables 10 - 17. On the left side of these tables there is a box where the absorption factor is across the top (ux = 0, 1, 2) and the gamma-ray energy is on the left. There were no Buildup Factors for energies less than 500 kilo-electron volts (keV) so, for the purposes of interpolation, it was assumed that the Buildup Factor was zero at zero energy.

First, Least Squares Fits were done for gamma-ray energies above and below the thorium gamma-ray energy. See, for example, Table 12 where fits were made for 500 keV and for 1000 keV. The Least Squares Fit equations are on the right side of the table [e.g., 0.162 + 2.14 (0.73169)]. These give the Buildup Factors for each energy.

The Buildup Factors computed by Least Squares Fit were then used with 2 point interpolation to get the Buildup Factor corresponding to the thorium gamma-ray energy. See, for example, Table 12 where 1.73 and 1.43 were computed for 500 and 1000 keV and used to get 1.72, the Buildup Factor for 510.8 keV. The Buildup Factors computed in this manner were tabulated on the right side of Table 9.

Adjustment to Cleanup Criterion

When calibrations were done by STS Consultants for the downhole logging probes, the criterion was based on 7.2 pCi/g. Since the cleanup criterion for Lakeshore East is 7.1 pCi/g, a slight adjustment had to be made by ratioing (7.1/7.2). The adjusted count rate is 5321 counts per 30 seconds. This calculation can be found below Table 18.

Adjustment for Yield

Since the adjustment for count rate is energy dependent, it was necessary to find out what fraction of the total count rate corresponded to each emission energy. First, the fraction of each radioactive decay corresponding to a thorium gamma-ray energy was found. For example, when lead-212 decays, a gamma-ray with an energy of 238.6 keV is emitted 44.6% of the time. These values, called Yields, are tablulated in Tables 18 and 19.

The total Yield is the sum of the individual Yields. Table 18 shows the total Yield for the Thorium Decay Series is 3.22 emissions. Below Table 18 a calculation is made that shows, at the cleanup criterion level of 5321 counts per 30 seconds, each emission is 1652 counts per 30 seconds. When this number is multiplied by the individual yields, the count rate corresponding to the cleanup criterion is found. These are tabulated in Table 19 under Column C. As a check, the column was added and agreed well within small roundoff errors (5324 versus 5321).

Changes in Exposure Rate Due to Absorption and Buildup

The equation listed at the beginning of this attachment can be adjusted to give the ratio of the initial count rate to the count rate after absorption and buildup.

$$X / X_o = B \exp(-[u/p] * x * p)$$

where

X / X_o = ratio of initial count rate to count rate after absorption and buildup (unitless)

B = Buildup Factor (unitless)

exp = base of natural logarithms

u/p = Mass Attenuation Coefficient (cm^2)

x = thickness of absorber (cm)

p = density of absorber (g/cm^3)

Table 18 shows the input factors for this calculation at each energy and gives the ratio in the far right column.

Adjusted Count Rate

In Table 19 the initial count rates, by energy, are listed in Column C. When these are mulitiplied by the ratios, X / X_o, in Column D the adjusted count rate by energy is obtained. The sum of the adjusted, energy dependent, count rates is 3176 counts per 30 seconds.

3176 counts per 30 seconds is the count rate for 7.1 pCi/g, corrected for 3 inches of water.

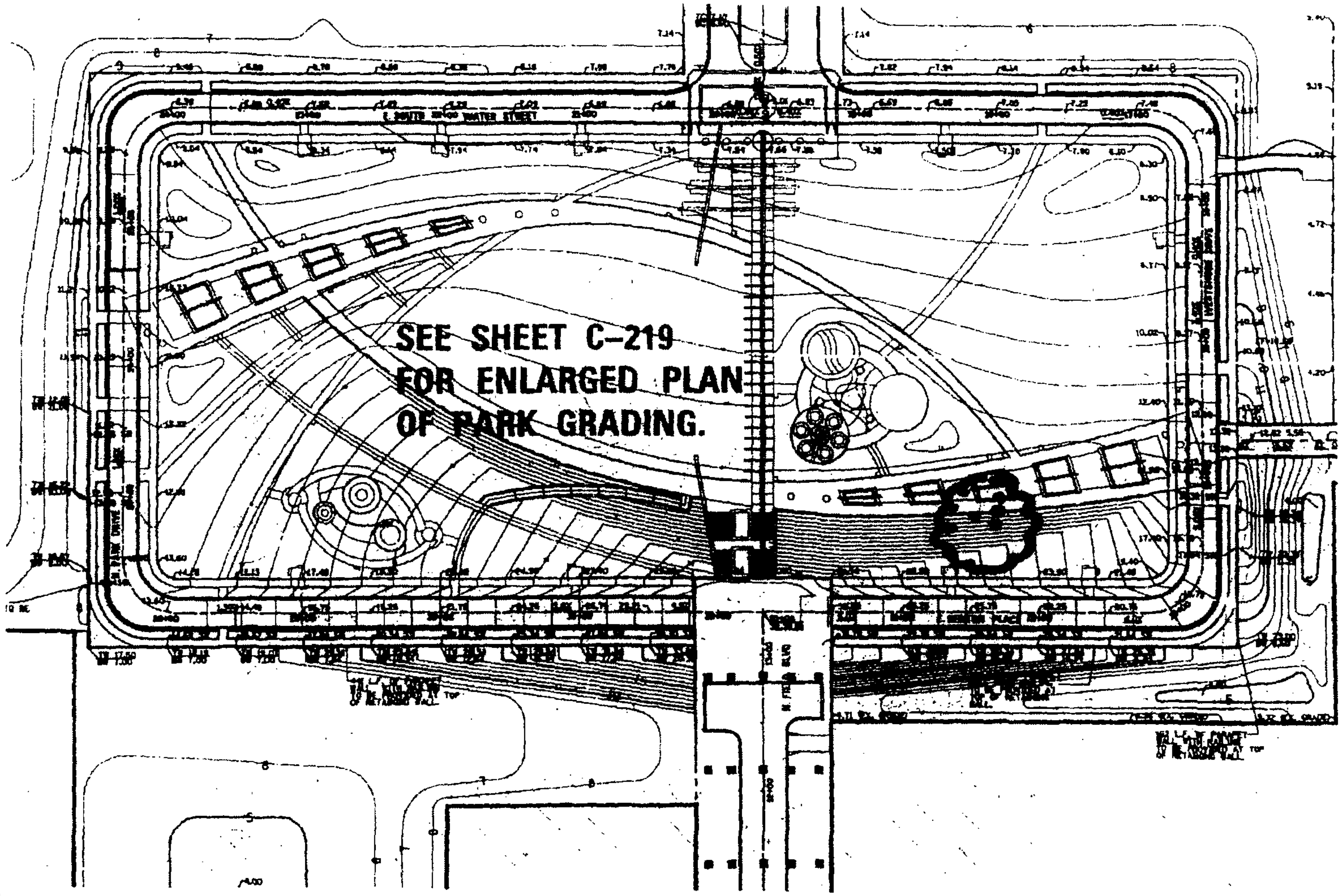
SEE SHEET C-219
FOR ENLARGED PLAN
OF PARK GRADING.
E. SOUTH WATER STREET

Table 1: Thorium Gamma Emission Energies and Yields

Radio-nulclide	Emission Energies (keV)	Yield (unitless)
Pb-212	238.6	0.446
Ac-228	338.4	0.120
Tl-208	510.8	0.216
Tl-208	583.1	0.858
Tl-208	860.4	0.120
Ac-228	911.1	0.290
Ac-228	968.9	0.175
Tl-208	2615	0.998

From: Publication 38
International Commission on Radiological Protection
"Radionuclide Transformations, Energy and Intensity of Emissions"

Table 2: Mass Attenuation Coefficients

Emission Energy (keV)	Mass Attenuation Coefficient (cm^2/g)
100	0.171
150	0.151
200	0.137
300	0.119
400	0.106
500	0.0968
600	0.0896
800	0.0786
1000	0.0707
1500	0.0575
2000	0.0494
3000	0.0397
4000	0.0340

From: Radiological Health Handbook

Figure 1: Mass Attenuation Coefficients versus Gamma Emission Energy

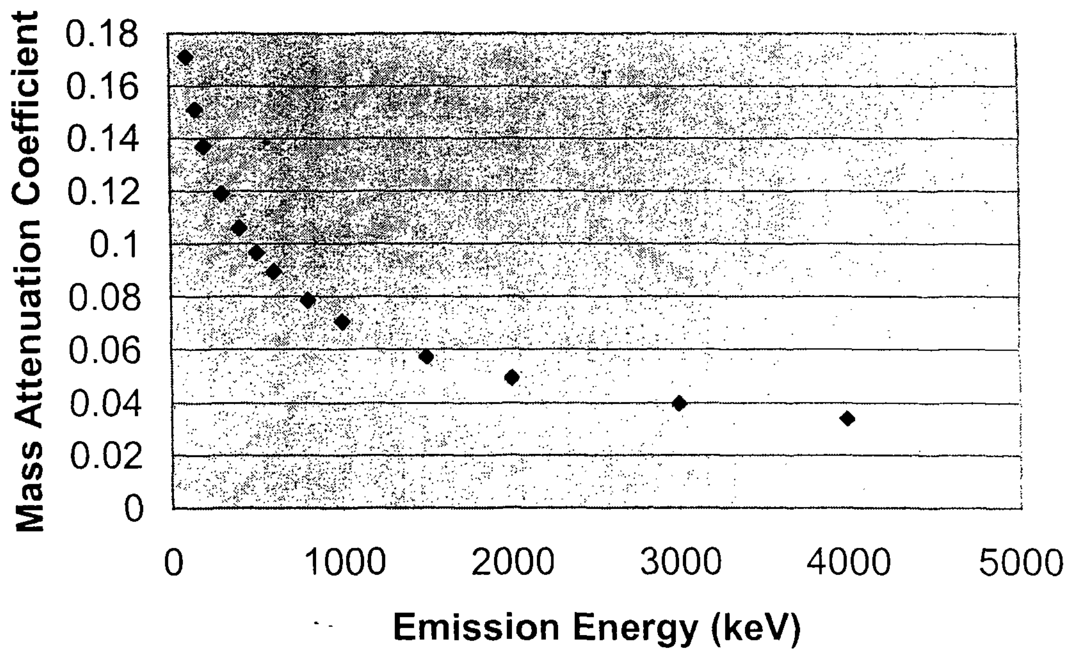

Table 3: Least Squares Fit for Mass Attenuation Coefficient

Energy Range for Least Squares Fit (keV)			Least Squares Fit a	+	b	*	Emission Energy (keV)	=	Mass Attenuation Coefficient (cm2/g)	Mean Mass Attenuation Coefficient (cm2/g)
150	-	300	0.181	+	-2.086E-04	*	238.6	=	0.131	0.131
200	-	400	0.167	+	-1.550E-04	*	238.6	=	0.130	
200	-	400	0.167	+	-1.550E-04	*	338.4	=	0.115	0.114
300	-	500	0.152	+	-1.110E-04	*	338.4	=	0.114	
400	-	600	0.152	+	-1.110E-04	*	510.8	=	0.095	0.095
500	-	800	0.126	+	-5.986E-05	*	510.8	=	0.095	
400	-	600	0.138	+	-8.200E-05	*	583.1	=	0.090	0.091
500	-	800	0.126	+	-5.986E-05	*	583.1	=	0.091	
600	-	1000	0.117	+	-4.725E-05	*	860.4	=	0.076	0.076
800	-	1500	0.101	+	-2.942E-05	*	860.4	=	0.076	
600	-	1000	0.117	+	-4.725E-05	*	911.1	=	0.074	0.074
800	-	1500	0.101	+	-2.942E-05	*	911.1	=	0.074	
600	-	1000	0.117	+	-4.725E-05	*	968.9	=	0.071	0.072
800	-	1500	0.101	+	-2.942E-05	*	968.9	=	0.072	
1500	-	3000	0.07391	+	-1.156E-05	*	2615	=	0.044	0.044
2000	-	4000	0.06413	+	-7.70E-06	*	2615		0.044	

Table 4: Mass Attenuation *Coefficient* by *2 Point* Interpolation and Comparison to Mean Mass Attenuation Coefficient by Least Squares Fit

Energy (keV)	Mass Attenuation Coefficient--- By 2 Point Interpolation (cm2/g)	Mean Mass Attenuation Coefficient---By Least Squares Fit (cm2/g)
200	0.137	
238.6	**0.130**	0.131
300	0.119	
300	0.119	
338.4	**0.114**	0.114
400	0.106	
500	0.0968	
510.8	**0.0960**	0.0954
600	0.0896	
500	0.0968	
583.1	**0.0908**	0.0906
600	0.0896	
800	0.0786	
860.4	**0.0762**	0.0760
1000	0.0707	
800	0.0786	
911.1	**0.0742**	0.0741
1000	0.0707	
800	0.0786	
968.9	**0.0719**	0.0719
1000	0.0707	
2000	0.0494	
2615	**0.0434**	0.0438
3000	0.0397	

Table 5: Linear Absorption *Coefficient and* Buildup Factor For 500 keV

Emission Energy (keV)	ux	B
500	1	2 63
	2	4 29
	4	9 05
	7	20 0
	10	35 9

Figure 2: Linear Absorption Coefficient versus Buildup Factor for 500 keV

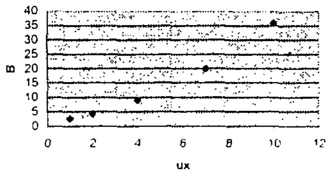

Table 6: Linear Absorption Coefficient and Buildup Factor For 1000 keV

Emission Energy (keV)	ux	B
1000	1	2.26
	2	3 39
	4	6.27
	7	11 5
	10	18.0

Figure 3: Linear Absorption Coefficient versus Buildup Factor for 1000 keV

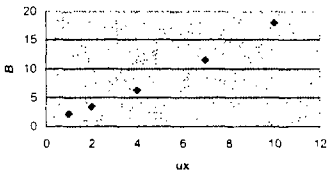

Table 7: Linear Absorption Coefficient and Buildup Factor For 2000 keV

Emission Energy (keV)	ux	B
2000	1	1 84
	2	2.63
	4	4.28
	7	6.96
	10	9 87

Figure 4: Linear Absorption Coefficient versus Buildup Factor for 2000 keV

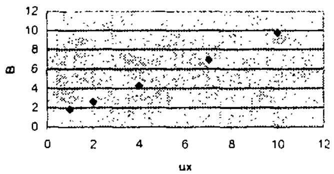

Table 8: Linear Absorption Coefficient and Buildup Factor For 3000 keV

Emission Energy (keV)	ux	B
3000	1	1 69
	2	2.31
	4	3 57
	7	5 51
	10	7 48

Figure 5: Linear Absorption Coefficient versus Buildup Factor for 3000 keV

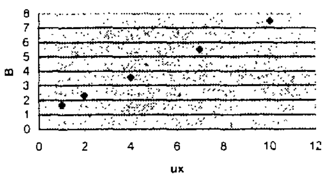

Table 9 Interpolated Plane Monodirectional Source Buildup Factor

Emission Energy (MeV)	Mean Emission Energy Mass Absorption Coefficient (u/p) (cm2/g)	Mean Emission Energy Linear Absorption Coefficient (ux) (unitless)	Interpolated Plane Source Buildup Factor (b) (unitless)
238.6	0.130	0.99100	1.09
338.4	0.114	0.86874	1.37
510.8	0.0960	0.73169	1.72
583.1	0.0908	0.69202	1.60
860.4	0.0762	0.58075	1.24
911.1	0.0742	0.56549	1.19
968.9	0.0719	0.54809	1.13
2615	0.0434	0.33097	0.58

ux = u/p * x * p

where

x = 3 inches = 7.62 cm

p = 1 g / cm3 = 1 g / cm3

Buildup Factor Interpolations

Table 10: Buildup Factor Interpolations for 238.6 keV

	0	0.99100	1	2	a +	b *	ux	=	
0	0	0	0.00	0					
238.6	0	**1.09**							
500	0	**2.28**	2.63	4.29	0.162	2.14	0.99100	=	2.28
					0	0.004565	238.6	=	1.09

Table 11: Buildup Factor Interpolations for 338.4 keV

	0	0.86874	1	2	a +	b *	ux	=	
0	0	**0.00**	0	0					
338.4	0	**1.37**							
500	0	**2.02**	2.63	4.29	0.162	2.14	0.86874	=	2.02
					0	0.004042	338.4	=	1.37

Table 12: Buildup Factor Interpolations for 510.8 keV

	0	0.73169	1	2	a +	b *	ux	=	
500	0	**1.73**	2.63	4.29	0.162	2.14	0.73169	=	1.73
510.8	0	**1.72**							
1000	0	**1.43**	2.26	3.39	0.188	1.70	0.73169	=	1.43
					2.023762	-0.000592	510.8	=	1.72

Table 13: Buildup Factor Interpolations for 583.1 keV

	0	0.69202	1	2	a +	b *	ux	=	
500	0	**1.64**	2.63	4.29	0.162	2.14	0.69202	=	1.64
583.1	0	**1.60**							
1000	0	**1.36**	2.26	3.39	0.188	1.70	0.69202	=	1.36
					1.921422	-0.000557	583.1	=	1.60

Table 14: Buildup Factor Interpolations for 860.4 keV

	0	0.58075	1	2	a +	b *	ux	=	
500	0	**1.40**	2.63	4.29	0.162	2.14	0.58075	=	1.40
860.4	0	**1.24**							
1000	0	**1.18**	2.26	3.39	0.188	1.70	0.58075	=	1.18
					1.634341	-0.000459	860.4	=	1.24

Table 15: Buildup Factor Interpolations for 911.1 keV

	0	0.56549	1	2	a +	b *	ux	=	
500	0	**1.37**	2.63	4.29	0.162	2.14	0.56549	=	1.37
911.1	0	**1.19**							
1000	0	**1.15**	2.26	3.39	0.188	1.70	0.56549	=	1.15
					1.594969	-0.000446	911.1	=	1.19

Table 16: Buildup Factor Interpolations for 968.9 keV

	0	0.54809	1	2	a +	b *	ux	=	
500	0	**1.33**	2.63	4.29	0.162	2.14	0.54809	=	1.33
968.9	0	**1.13**							
1000	0	**1.12**	2.26	3.39	0.188	1.70	0.54809	=	1.12
					1.550085	-0.000430	968.9	=	1.13

Table 17: Buildup Factor Interpolations for 2615 keV

	0	0.33097	1	2	a +	b *	ux	=	
2000	0	**0.61**	1.84	2.63	0.175	1.32	0.33097	=	0.61
2615	0	**0.58**							
3000	0	**0.56**	1.69	2.31	0.178	1.15	0.33097	=	0.56
					0.718412	-0.000053	2615	=	0.58

Table 18: Ratio of Adjusted to Original Count Rate

Emission Energies (keV)	Interpolated Plane Source Buildup Factor (b) (unitless)	Emission Energy Mass Absorption Coefficient (u/p) (MeV)	Thickness of Water Absorber (x) (cm)	Density of Water (p) (g/cm3)	Yield (unitless)	Ratio, Absorbed Exposure Rate (unitless)
238.6	1.09	0.130	7.62	1	0.446	0.40
338.4	1.37	0.114	7.62	1	0.120	0.57
510.8	1.72	0.0960	7.62	1	0.216	0.83
583.1	1.60	0.0908	7.62	1	0.858	0.80
860.4	1.24	0.0762	7.62	1	0.120	0.69
911.1	1.19	0.0742	7.62	1	0.290	0.68
968.9	1.13	0.0719	7.62	1	0.175	0.66
2615	0.58	0.0434	7.62	1	0.998	0.42
					3.22	5.05

Ratio = X / Xo = B exp(-[u/p] * x * p)

Total counts at 7.2 pCi/g 5396 counts / 30 seconds
Total counts at 7.1 pCi/g 5321

5321 / 3.22 1652

Table 19: Adjusted Count Rate for Cleanup Criterion

A	B	C	D	E	F
Emission Energy (keV)	Yield (unitless)	1652 * Yield (unitless)	Ratio, Absorbed Exposure Rate (unitless)	Column C * Column D (unitless)	Column E / Column C
238.6	0.446	737	0.40	298	
338.4	0.120	198	0.57	114	
510.8	0.216	357	0.83	296	
583.1	0.858	1417	0.80	1133	
860.4	0.120	198	0.69	137	
911.1	0.290	479	0.68	324	
968.9	0.175	289	0.66	189	
2615	0.998	1649	0.42	686	
	Total	5324	**Total**	3176	60%

Count rate equivalent to 7.1 pCi/g	=	3176 counts per 30 seconds